1978

Soil and Water Loss from Conservation Tillage Systems

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ABSTRACT

A rainfall simulator was used to evaluate the effects of six different tillage practices on soil and water losses from continuous corn for three soils in Iowa. Soil loss decreased as tillage decreased. Percent of soil covered by corn residue explained between 78 and 89 percent of the variance in erosion among tillage systems. The effect of non-uniformly distributed corn residue on controlling erosion was greater than expected based on a published mulch factor. Runoff amounts decreased as residue cover increased for two of the three soils studied. No critical slope length limits were found for the tillage practices, soils, slopes, and slope lengths studied except for till-planting on the Ida soil. As sediment concentrations increased, mean sediment size increased for one soil, decreased for a second soil, and was unrelated to sediment concentration for the third soil.

INTRODUCTION

Conservation tillage systems are important to meet goals for abating non-point sources of agricultural pollution, since economic analyses (Nicol et al., 1974; Seay, 1970) have indicated that the least costly way to limit soil losses is by conservation tillage practices. Conservation tillage practices leave part or all of the previous year's residue on the soil surface to decrease soil erosion.

Wischmeier (1973) published a mulch factor-crop residue relation for estimating the effects of crop residue on soil erosion. The mulch factor was the ratio of erosion with crop residue coverage to erosion with no residue coverage. Wischmeier's studies used nearly uniformly distributed wheat straw, but data for low mulch rates were limited, and no critical slope-length limits were determined. Wischmeier (1973) also published cropping-management factors, defined earlier (Wischmeier and Smith, 1965), for specific conservation tillage practices.

Our objectives in this study were to:

1 Determine the effects of corn residue on rates and amounts of runoff

2 Evaluate the mulch factor-residue cover relationship for non-uniformly distributed corn residue

3 Determine physical characteristics of eroded material

4 Determine critical slope-length limits for conservation tillage practices.

METHODS AND PROCEDURES

Three experimental sites were located on soil representing large areas of Iowa. Each site had a suitable area of nearly uniform slope that had been in row crops for several years. Table 1 gives the soil and slope characteristics of these sites.

A randomized complete block design with two replications was used for six tillage practices at each location:

1 Conventional—preplant tillage was moldboard plowing and double disking

2 Till-plant—no preplant tillage, planted with a till-planter (Wittmuss et al., 1971)

3 Disk—preplant tillage was double disking

4 Chisel—preplant tillage was chisel-plowing (twisted shank on 30 cm centers) followed by a light disking

5 Ridge—no preplant tillage, planted on top of existing ridge

6 Fluted coulter—no preplant tillage, planted in opening of fluted coulter traveling in old row.

All tillage was performed parallel with the row, with rows up-and-down-hill. The same corn planter (with disk openers) was used on all treatments, except for the till-plant for which a commercially available till-planter was used.

A rotating-boom rainfall simulator as described by Swanson (1965), was used to apply the simulated rainfall on 3.05 x 10.67 m plots. The physical arrangement permitted the testing of 2 tillage treatments simultaneously. Rainfall was simulated within 11 to 35 days after planting, and all plots for a single location were tested within 8 days.

A complete simulation consisted of a 1.4 h storm at an intensity of 6.35 cm/h (which for 1.4 h has about a 50 yr return period in central Iowa) in the afternoon (storm 1), followed the next morning by a 1 h storm at 6.35 cm/h (storm 2), and a 1/2 h storm at 12.7 cm/h (storm 3).

Slope length was simulated by adding flow at the upper end of the plot, with and without simulated rainfall, using a method similar to that of Swanson and Dedrick (1966). Generally, flow was added at three rates, the first rate (about 6.35 cm/h) with and without simulated rainfall at 6.35 cm/h. Later rates were about two and three times the initial rate, both with simulated rainfall at 6.35 cm/h. About 45 min were needed to complete the simulation. The slope length for each flow rate was computed as the length required to generate a flow rate equal to the flow rate added, plus

Article was submitted for publication in March 1977; reviewed and approved for publication by the Soil and Water Division of ASAE in October 1977. Presented as ASAE Paper No. 75-2032.

Journal Paper J-8230 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Projects 1853 and 1941; and the North Central Region, USDA-SEA.

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TABLE 1. CHARACTERISTICS OF SOILS AND AREAS STUDIED.

Soil*	Location	Average slope	Clay	Silt	Very fine sand	Sand	Organic† matter	Soil‡ erodibility value K	USDA-SCS Hydrologic soil group
			Primary particles†						
	City	percent						t/ha/EI	
Kenyon	Jesup	4.8	16	26	6	58	3.2	0.19	C
Tama	Kellogg	4.7	25	73	1	2	2.4	0.53	B
Ida	Castana	12.2	22	74	2	4	2.0	0.47	B

*For detailed soil descriptions see Soil Survey Investigations Report #3, Soil Survey Laboratory Data and Description for Some Soils of Iowa. USDA, Soil Conservation Service, 1966.
†From top 15 cm
‡E is rainfall energy per unit area and I is rainfall intensity. For conversion to English system, divide K by 1.3.

10.67 m. Interrill erosion rate was computed as the difference between erosion rate at the end of storm 2 and the erosion rate when flow was added with no simulated rainfall. Rill erosion rate for the bottom 10.67 m for a given slope length was computed as the difference between erosion rate for that slope length and interrill erosion.

Runoff flow rates were determined gravimetrically, every 5 min during the first 30 min of runoff for each storm, and every 10 min thereafter. The first measurement was made shortly after runoff began, and the last 1 min prior to the end of the storm.

One-liter samples were collected for gravimetric sediment concentration determinations for a 2 to 3 min period after each flow rate measurement (except for a 1/4 to 1/2 min period for the last sample of a storm).

Size distributions (not primary particle-size distributions) of the eroded material were determined on a randomly selected sample (excluding the first and last sample) from each storm with a hydrometer, using procedures like those used by Day (1965) except no chemical dispersant was used. Within 24 h after the storm, the sample was poured into a 1000-mL graduated cylinder and stirred for 1 min with a brass plunger. Then a hydrometer was inserted and read immediately, and at various times during settling. After the hydrometer analysis, the sample was returned to its container for sediment concentration determination.

Residue coverage of each plot was measured before simulation using 35 mm slides of eight 76 x 76 cm^2 areas with a 5.1 x 5.1 cm superimposed grid. The percentage of grid intersections over residue was determined from the projected slides. Residue coverage was computed as the average of the eight values. Additional measurements (Length, L, of surface residue under a 0.76 m line was measured; residue coverage = 100 L/0.76) were made at six locations in each plot. These two methods gave similar results.

TABLE 2. RESIDUE COVER FOR TILLAGE PRACTICES STUDIED.

Soil	Conven-tional	Till-plant	Chisel	Disk	Ridge	Coulter
	Tillage practice					
	Percent					
Kenyon	2	10	12	24	27	46
Tama	4	20	21	21	31	63
Ida	9	17	23	45	46	58

RESULTS AND DISCUSSION

Most results in this paper are presented as statistical relations between soil and water losses and residue cover, rather than as losses from specific tillage systems. This method of analysis neglects other effects of tillage than residue cover and, in fact, if residue cover and other variables are correlated, may mask the effect of these other variables. The study was not designed to evaluate the effect of residue cover independently of tillage.

Table 2 shows the average residue coverage for each tillage practice for each soil. Fig. 1 shows total runoff from all storms, average sediment concentration, and total soil loss, versus residue coverage for each location.

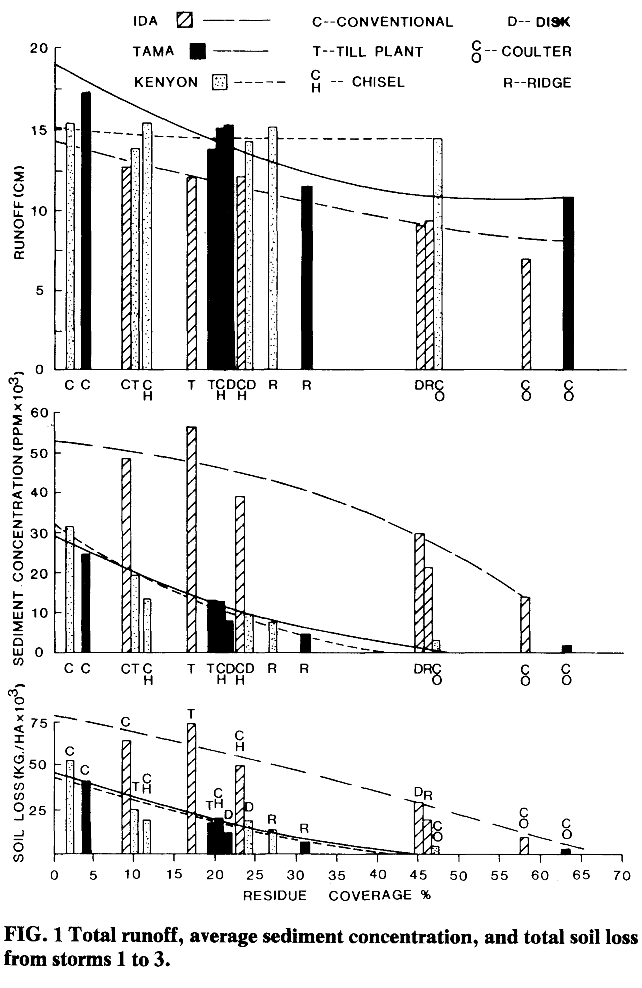

FIG. 1 Total runoff, average sediment concentration, and total soil loss from storms 1 to 3.

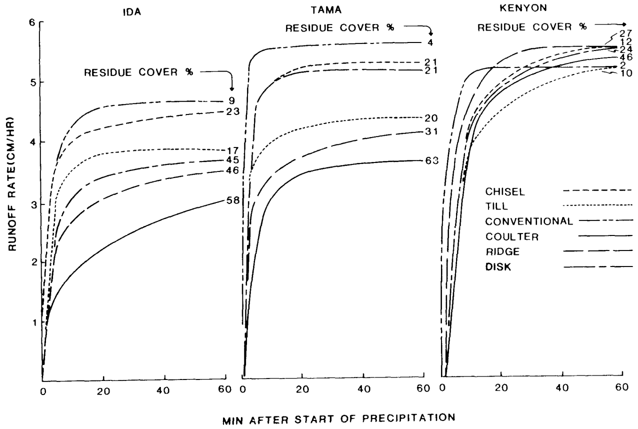

FIG. 2 Flow rate vs. time for storm 2.

Also shown are lines of the best quadratic relations of residue coverage to these three measured quantities. Best fit quadratic relations were determined using least squares regression techniques.

Total runoff from the Ida soil ranged from only 34 percent of the total applied precipitation for the coulter treatment to 60 percent for the conventional tillage, while total runoff from the Tama and the Kenyon soils ranged from 51 to 81 percent and from 65 to 73 percent for the same treatments. The quadratic relations between residue coverage and runoff were significant for the Ida ($r^2 = 0.73$) and Tama soils ($r^2 = 0.45$), but not for the Kenyon soil ($r^2 = 0.06$). The quadratic relationship was better than a linear relationship for the Tama soil, but not for the Ida soil.

Runoff rates versus time are shown in Fig. 2 for storm 2 for each treatment for each soil. For the Ida and Tama soils, treatments with the most residue coverage usually had the lowest runoff rates and the slowest rise in runoff rates, while for the Kenyon soil, runoff rates also rose more slowly as residue coverage increased, but final runoff rates and total runoff were unrelated to residue cover.

The till-plant treatment behaved differently from other treatments. The till-plant treatment had the lowest runoff rate for the Kenyon soil, and runoff rates on the Ida and Tama soils were much less than rates for other treatments having about the same cover. The till-plant treatment, after planting, left bare about 40 percent of the area with the remainder covered by an unconsolidated mixture of soil and residue deposited upon the original, untilled, soil surface. While measurements showed the till-plant treatment with low residue cover (Table 2), the unconsolidated material increased surface storage available under the till-plant treatment as compared with other treatments, as shown by the delayed rise in flow rates. Much of the increased water stored infiltrated the Ida and Tama soils and some infiltrated the Kenyon soil.

Sediment concentration in runoff generally correlated well with residue cover (Fig. 1). Quadratic relations (shown as lines in Fig. 1) explained 81, 93, and 84 percent of the variance in sediment concentration for the Ida, Tama, and Kenyon soils, respectively. This relationship was significantly better than linear for the Kenyon and Tama soils, but not for the Ida soil. Removing the till plant treatment from the analysis on the Ida soil shifted the best fit line, but only slightly improved the goodness of fit to the data. Because of the much greater slope of the Ida soil (Table 2), sediment concentrations were expectedly much greater than those for the other soils.

The till-plant treatment for the Ida soil was an apparent anomaly, being the only case where sediment concentration from any treatment for any soil exceeded the sediment concentration from the conventional treatment. For the other two soils, sediment concentration from the till-plant treatment was usually not much different than that of other treatments with similar cover. Excessive rilling in the wide bare area where the seed was planted by the till-plant treatment was apparent on the Ida soil. Moldenhauer et al. (1971) reported that runoff came directly down the crop row on a till-plant treatment planted up-and-down hill. Evidently, the Ida soil is more susceptible to rill erosion than either the Tama or Kenyon, or the difference in slopes between the soils caused the difference in effect of till-planting on sediment concentration in runoff.

Total soil loss from the first three storms, adjusted to common rainfall and LS factors (Wischmeier and Smith, 1965) for each location, is shown in Fig. 1. The quadratic relations shown explained 78, 89, and 83 percent of the variance in soil loss for the Ida, Tama, and Kenyon soils, respectively. These values indicated that soil loss, like sediment concentration, was highly dependent on residue cover.

Total soil loss was higher for the till-plant treatment on the Ida soil with a 12 percent slope than for the conventional treatment, but was lower than the conventional for the Tama and Kenyon soils with about a 5 percent slope. A practice that channeled the water like the till-planting would cause much erosion if resistance to rill erosion was low, but results would likely be very different if rows were not up-and-down hill.

We developed a mulch factor-residue cover relation for each soil by dividing the best fit quadratic relation for soil loss by the intercept of each curve (Fig 3.). Since dividing by a constant does not affect r^2, the mulch factor-residue cover r^2 is the same as that for soil loss-residue cover. Also, by dividing individual soil loss data points for each location by the intercept for that location, we combined all the data to obtain one mulch factor-residue cover relationship for all three soils (Fig. 3).

We used data presented by Wischmeier (1973) to derive a mulch factor-residue cover relation ($r^2 = 0.93$) similar to the relation presented above (Fig. 3). The published data were for tillage practices on the contour subjected to rainfall simulation during the first 30 days after planting.

Fig. 3 shows considerable variability in the data; however, most data points obtained in this study with non-uniformly distributed corn residue fell well below the published mulch factor-residue cover relation derived using uniformly distributed wheat straw. Evidently, corn residue more effectively reduces erosion than does wheat straw, and corn residue appears to be very effective even for low residue coverages. Moreover, apparently there is a soil and/or slope interaction with residue coverage.

Knowing the size of eroded materials is important when predicting the effectiveness of sedimentation basins

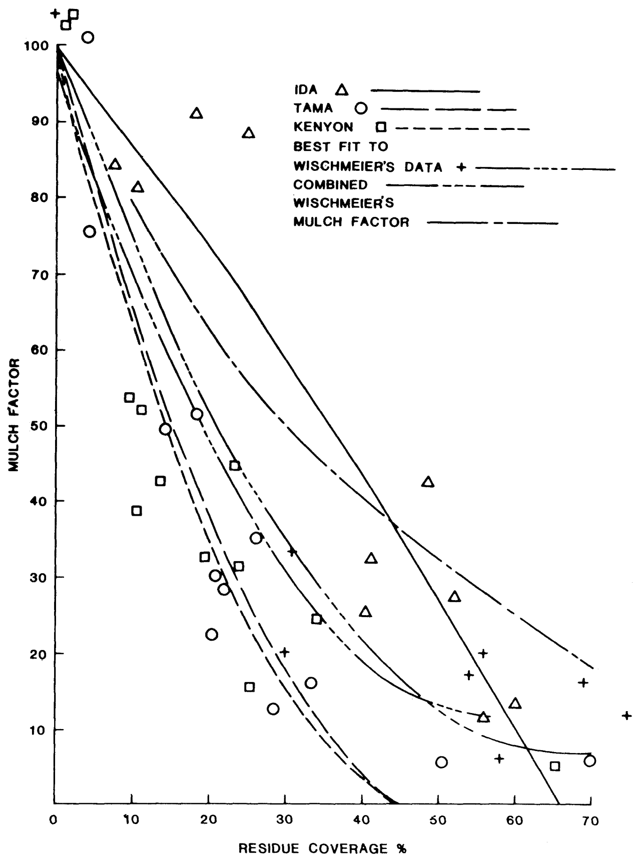

FIG. 3 Mulch factor-crop residue relations derived using data from this study and data published by Wischmeier. Also shown in the mulch factor-crop residue relation published by Wischmeier.

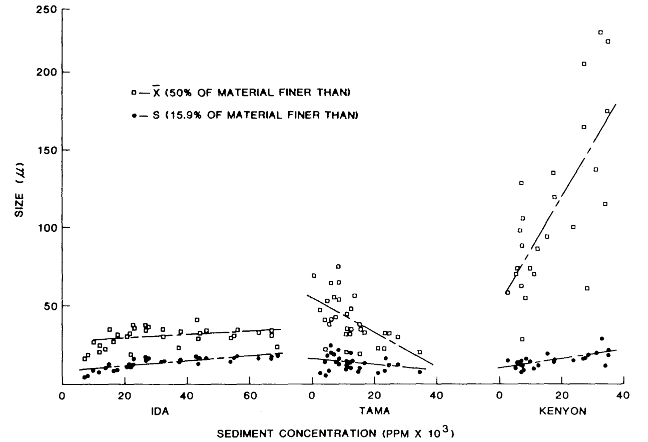

FIG. 4 Physical characteristics of eroded sediments vs. sediment concentration.

and in predicting sediment transport. We correlated characteristics of the size distributions of eroded material (including both aggregates and particles) with sediment concentration, erosion rate, and flow rate using least square regression methods. There was no significant linear correlation between $\overline{X}$ (sediment size at which 50 percent of the sediment was finer) or S (sediment size at which 15.9 percent of the sediment was finer), and flow rate. In every case, correlations were better when sediment concentration was the independent variable than when erosion rate was the independent variable. There was no significant correlation between erosion rate and $\overline{X}$ for any soil. Both $\overline{X}$ and S vs. sediment concentration are shown in Fig. 4 for each soil.

The regression analyses indicated a significant correlation between $\overline{X}$ and sediment concentration for the Kenyon and Tama soils, and between S and sediment concentration for all soils (r^2 from 0.16 to 0.61, usually significant at 1 percent level). The best fit linear relations between $\overline{X}$ or S and sediment concentration are also shown in Fig. 4.

Size distributions of eroded material varied widely between soils. As shown in Fig. 4, for the Ida soil, as sediment concentration increases, $\overline{X}$ increased only slightly, and apparently at sediment concentrations in excess of 15000 ppm, $\overline{X}$ is constant. Also, S seems to increase only slightly at concentrations over 15000 ppm. Thus, the eroded Ida soil at concentrations over 15000 ppm has constant physical characteristics and the source(s) of eroded material remained constant, or, all sources of eroded material yielded similar materials.

Material eroded from the Tama soil became finer and more uniform as sediment concentration increased. No explanation for this is apparent. As residue cover increases, and sediment concentrations and runoff velocity decrease (Meyer et al., 1970), so does the total rainfall energy impacting the soil surface. Hence there is less energy to break up soil aggregates which could be a factor for loosely bound soil aggregates.

The Kenyon soil behaved much differently than either the Ida or Tama soils. Sediment eroded from the Kenyon soil was generally much coarser, and as sediment concentrations increased, $\overline{X}$ increased rapidly with only a relatively minor increase in S. Although Kenyon soil differs greatly in texture from the other soils (Table 1), its slope was about that of the Tama soil. As sediment concentrations increased, the eroded Kenyon soil had a size distribution more nearly that of the primary particle size distribution of the soil in place than did the eroded Tama or Ida soils.

Erosion rates vs. slope length are shown in Fig. 5 for each treatment for each soil. As a reference, the length factor (L), for the Universal Soil-Loss Equation (Wischmeier and Smith, 1965) is shown for several erosion rates.

Relationships between erosion rate and slope length in Fig. 5 are usually linear with little apparent justification for non-linear relationships. Meyer et al. (1976) exhibited several non-linear relationships for mulches of stone, straw, and wood chips, but nearly all their data was for erosion rates at least twice those of the till treatment for the Ida soil, and several were over 100 times rates shown in Fig. 5. The slope length relationship used in the Universal Soil-Loss Equation exhibits only minor curvature in the range of our data, and our precision in this part of the study was not adequate to detect the small curvature expected.

For each soil, increased residue cover resulted in a lower erosion rate, and a slope length-erosion rate relation of lower slope. However, the slope length-erosion rate relationships varied greatly between soils. The effect of an increase in slope length on erosion rate was greater for the Ida soil than for the Kenyon or Tama soils, which was expected since the average slope of the Ida soil was more than twice that of the Kenyon or Tama soils. The major difference between the Kenyon and Tama soils was unexpected; an increase in slope length on the Kenyon soil resulted in an increase in

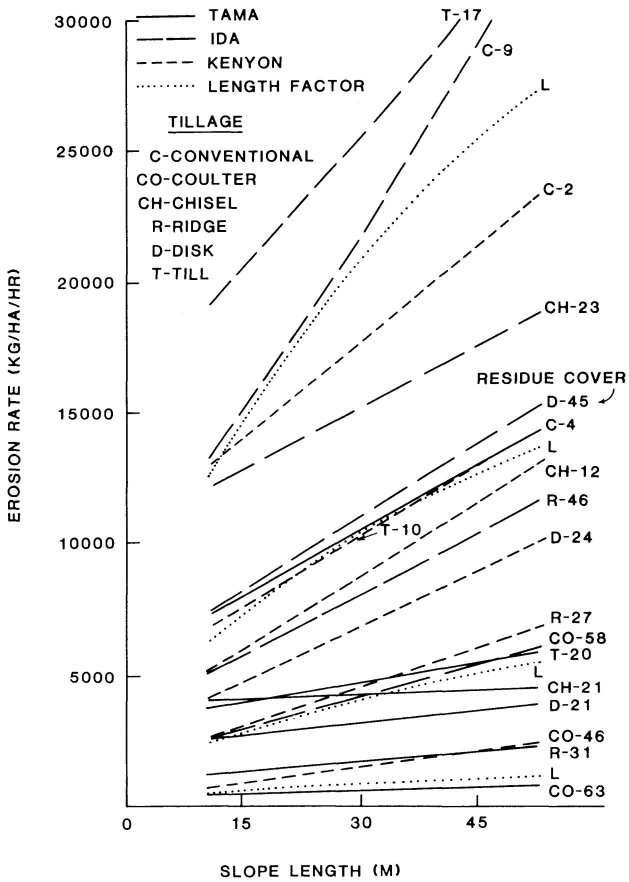

FIG. 5 Effect of slope length on erosion rate. Data from storms where water was added at upper end of plot, and a simulated rainfall of 6.35 cm/hr.

erosion rate averaging nearly 6 times the increase in erosion rate for the Tama soil. Evidently, these two soils differed considerably in their resistance to rill erosion.

For the lengths, slopes, and soils studied, no breakdown of practice effectiveness was observed, such as reported by Wischmeier (1973), for field conditions, except for till planting on the Ida soil. The lengths simulated were apparently too short, for the conditions studied, to cause practice failure under nearly all conditions. Even for till-planting on the Ida soil, failure did not sufficiently alter the slope length-erosion rate relation so that the failure was apparent from an examination of the data.

When we simulated slope length, soil loss under the till treatment was similar to the conventional treatment for the Ida soil, but was much lower for the Kenyon and Tama soils.

SUMMARY AND CONCLUSIONS

A rotating boom rainfall simulator was used to evaluate the effect of tillage systems on soil and water losses. For two of the three soils tested runoff was reduced by tillage systems that left a residue cover on the soil.

Sediment concentration in runoff water was well correlated with the percentage of surface area covered by crop residue; total soil loss also correlated well with residue cover. Apparently, residue cover adequately explains soil loss from most tillage systems during the cropping period when crop canopy is not significant.

The mulch factor-crop residue relation, derived by Wischmeier (1973) from studies using uniformly distributed wheat straw at high coverages, seems to underestimate the effectiveness of non-uniformly distributed corn residue.

As sediment concentration increased mean sediment size increased for a soil with a high percentage of sand, but decreased for a soil with a much lower percentage of sand, and was unrelated to sediment concentration for a third soil.

We observed no critical length beyond which a residue cover was ineffective in reducing erosion; the relationship between residue cover and erosion was inversely proportional for both short and long slope lengths for all soils. However, failure of the till-planting method was visually observed under the up-and-down hill study conditions.

Erosion from the till-planting method was greater than that from conventional tillage for the Ida soil but less than that from conventional tillage for the Tama and Kenyon soils under the up-and-down hill conditions of this study. Apparently there was a tillage practice-slope-soil interaction. The erosion from till planting would likely be much less than that from conventional planting if field operations were contoured.

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